SOME PRACTICAL PROBLEMS IN FILTRATION PLANT OPERATION[1]

By Lewis I. Birdsall

It has occurred to the author that certain practical problems encountered by him during his experience in the management of mechanical filtration plants may arise elsewhere, and, therefore, a description of some of these problems and their solution may be of general interest to designing engineers and superintendents of filtration.

Coagulant piping. One of the greatest problems lies in furnishing an ample supply of coagulant solution to the right place at the right time when it is most needed. When the author assumed charge of the new Rock Island filter plant in 1911, a 1½-inch lead-lined iron pipe carried the alum solution some 300 feet to the far end of the coagulating basins, the pipe being laid under the water of the basin. The available head for producing the flow of alum solution was approximately 4 feet. It was soon found that this line would not carry the required amount of solution because of the clogging of the pipe by deposits from the alum, and also because of entrained air. A hydraulic ejector was placed in the line, but while it served to remove the air it did not remove the deposits in the pipe.

More serious difficulties arose when the alum solution began to appear where least expected. Investigation showed leaks at the threaded joints where lead did not meet lead, and also at the bad spots in the piping where the lead lining was deficient. The line was mostly under water, so the difficulties were increased. Whole lengths of pipe were replaced, but the troubles continued. The lead-lined pipe was replaced with a 2-inch composition conduit which was guaranteed to be unaffected by the alum solution. So it was, but when the water in the basin began to warm up in the spring the conduit expanded and broke at the joints. Expansion joints of rubber hose were inserted, but when cold weather came the conduit contracted and pulled apart. Lead and brass pipe were then tried,

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but these clogged up with deposits of slimy material. C. R. Henderson, manager of the Davenport Water Company, then suggested the use of four-ply rubber hose, which was installed in 50-foot lengths, and the troubles were eliminated. Whenever the hose clogged up it was removed, one length at a time, trod upon to loosen the deposits and then flushed out with water under pressure.

It is only fair to state that recent information from Rock Island shows that fibre conduit is satisfactory when encased in concrete or other suitable material, and is not subjected to extreme changes in temperature.

All coagulant lines in the Minneapolis filtration plant were of 2-inch lead pipe with brass couplings, laid with a slope of 1 inch in 10 feet on horizontal runs. The discharge lines from the solution pumps to the overflow tanks which supply the chemical feed controllers gave little trouble from clogging, but the gravity flow lines from the controllers soon began to clog up, as did the pipes at Rock Island. The long runs of lead pipe were difficult to remove for frequent cleaning, and it became more and more difficult to get proper coagulation.

It was decided in 1914 when making additions to the original plant, to install open coagulant piping in place of lead pipe on horizontal runs. Consideration was given to open tile laid in concrete and to a concrete channel; but the scheme finally adopted was 4-inch cast iron pipe open at the top and made from plans prepared by W. N. Jones, erection engineer. The author is again indebted to C. R. Henderson for the suggestion of open coagulant piping, which has solved all of the difficulties formerly experienced. It is readily accessible for cleaning and for painting several times each year with a high grade of graphite or asphalt paint. No leaks have occurred in the pipe during the three years that it has been in service.

The chemical composition of the deposit occuring in the alum lines at Minneapolis may be of interest. The following analysis of a sample was made in the laboratories of the General Chemical Company, Chicago; $Fe_2(SO_4)_3$, 22.60 per cent; $Fe(OH)_3$, 23.11 per cent; $Al(OH)_3$, 24.93 per cent; SiO_2, 12.32 per cent; H_2O, 15.96 per cent; CaO, none; Cl, trace.

The high cost of brass has led to the use of iron flanges for connecting lead to lead or lead to rubber hose on the discharge lines from the coagulant solution pumps. The iron flange is pushed on to the lead pipe, the end of which is then expanded with a mandrel and

bent over so that a lead-to-lead coupling is obtained at slight expense.

Chemical solution agitators. The agitating devices for the chemical solution tanks were originally of the two-blade impeller type driven by a 3-inch by 13-foot hollow vertical shaft, direct-connected to a 2 horse-power motor running at 1720 revolutions per minute. The high rate of speed of the impellers produced excellent agitation of the solutions, but caused the bending of the drive shafts and armature shafts in the motors. Corrosion of the steel shafting and bronze thrust bearing made much trouble and a high cost of maintenance.

It was decided to reduce the speed of the agitators to approximately 600 revolutions per minute by means of reduction gears, to replace the 6-inch impeller blades with wooden blades 3 feet long, and to make steady bearings at the center of the vertical drive shafts. These changes eliminated some of the troubles, but there still remained the corrosion of the bronze bearing and the steel shafts. Also the agitators were very noisy, the motors having been set on a steel deck supported by I-beams over the center of the tanks.

The 4-inch hollow steel shafts were replaced with square 4 × 4-inch oak shafts, the two blades made of one piece of oak and having an upward thrust at an angle of 45 degrees from the horizontal. One horizontal motor of 2 horse power and 1120 revolutions per minute replaced the three vertical motors, and by means of shafting, clutches and worm drive, the speed of the impellers was reduced to approximately 10 revolutions per minute. The blades of the impellers were lengthened so as to reach within 6 inches of the sides of the tanks. The results have been very satisfactory; the noise has been eliminated, one motor does the work of three, there is no more trouble with the shafts or impellers, and the solution is amply agitated.

Painting concrete. The inside surfaces of all concrete chemical solution tanks are kept well covered with a good grade of asphalt or graphite paint. It was found that the alum solution was dissolving the limestone aggregate and otherwise decomposing the concrete walls of the tanks. Graphite paint seems to give better service than asphalt, the latter gradually dissolving off.

The aesthetic side of a filter plant. It has occurred to the author that more attention might well be given by designing engineers to the aesthetic side of a water purification plant. By this is meant

giving to the inside of a filter plant an appearance of light and cleanliness through the liberal use of white tile and paint. The added expense to the municipality or private water company would be more than offset by the favorable impression created in the minds of the water consumers, who in Minneapolis, for example, visit the plant to the number of 10,000 yearly. Most filtration plants present a creditable appearance externally, proper attention having been given to architectural design and landscape gardening. But inside the plant it is usually gloomy and oppressive to the casual visitor. What a difference there would be in the impressions given if the sides of the filter boxes above the sand line were covered with white tile, the floor of white tile and a wainscoting of tile extended around the side walls of the filter house. White paint on the walls above the wainscoting and on the ceiling would reflect light downward into the filter, and the whole appearance of the place would be changed. There would be an added incentive to the employees to keep the place absolutely clean and there would be no more spitting in dark corners.

Some work along this line is being done in the Minneapolis plant. The concrete floors, which dusted up and were rough in spots, have been painted with concrete floor paint. This paint has not only improved the appearance of the floor and stopped the dusting, but has also added a desirable springiness that is much appreciated by the filter operators. The walls inside the plant are of white brick, and these are being painted with flat white wall paint.

It has been found that the arc lamps originally installed over the filters are not satisfactory for lighting them. Clusters of Mazda lamps are being substituted in new construction work and electric lights placed about the filters at the side of the walks so that the entire surface of the filters may be observed when washing at night.

Portable valve-opening motor. The sluice gates installed in the gate house of the original plant are hand-operated and it required considerable labor and time to open and close them. When two new coagulation basins were added in 1914, they were equipped with sluice gates, the stands of which were geared so as to be opened or closed in less than five minutes by a portable electric motor. The outfit consists of a 3 horse-power 440-volt, 3-phase electric motor running at 660 revolutions per minute, with control board and extension cable, all mounted on a truck so arranged that the rawhide pinion of the motor can be engaged with the gear of the stand. The truck is fastened to the stand by quick-adjusting bolts.

Electric current is obtained from suitable contacts arranged in the wall of the building. The motor is equipped with proper devices to prevent jamming of the gates, and has given entire satisfaction.

Sterilization of distribution mains. Sterilization by means of hypochlorite of lime of all distribution mains larger than 12 inch, following their installation and previous to their being placed in service, is now practised in Minneapolis with gratifying results. Experience has shown that flushing a pipe larger than 12 inches does not entirely remove polluting material which has entered the pipe previous to or during the laying of the same. If the pipe is large enough to permit, it is thoroughly brushed out and then as it is slowly filled hypochlorite is added at the filling end in amounts large enough to leave a large excess of free chlorine, as shown by the tests. Bacteriological analyses are made later to see that the water has been sterilized from one end of the pipe to the other. After allowing the pipe to stand full for several days, the water is completely drained out and the pipe flushed with fresh water if suitable drains are available. Otherwise the pipe is flushed out through hydrants until tests show the water to be free from the chlorine added.

Automatic chemical feed controllers. Earl chemical feed controllers were installed as a part of the equipment in the Minneapolis filtration plant, and they have proved to be of the greatest value in operation. Soon after they were put in service trouble developed with the electrical control apparatus. The hydraulic valves on the supply line were controlled by pilot valves and these in turn by electro-magnets through ingeniously arranged contact points on the ends of the balanced arm at the top of each machine. The electromagnets would stick at times unless carefully watched and either would cause the hydraulic valves to close off entirely, thus shutting off the entire supply of chemical solution, or else the valves would open wide and the machines overflow.

One other trouble that developed was the continual chattering of the electrical apparatus, and the constant movement up and down of the hydraulic valves, thus causing a continual fluctuation in the levels of the system. Also it was necessary to keep a small triplex pump running constantly to supply pressure for the hydraulic valves on these machines and a ten-volt direct-current motor-generator machine to supply current.

It occurred to the author early in 1913 that these difficulties might

be eliminated by using balanced float valves and hydraulic control throughout. An experimental controller was made from soil pipe and the plan tried out with success. All of the electrical apparatus was then removed from the master and other controllers, and balanced float valves installed. The master controller was equipped with two $\frac{3}{4}$-inch balanced float valves, one connected with the water pressure line, so as to supply water to the right hand tube of the master controller and the other to a drain so as to lower the water level in the same tube. The two balanced valves were then connected with a $\frac{1}{4}$-inch rod attached to the balance arm on the master controller in such a manner that as one valve opens the other closes. The relative adjustment of the two valves was secured by turnbuckles, and the balanced arm on top of the controller was weighted so as to compensate for the pull exerted on the opposite side of the fulcrum by the two valves.

Each of the three alum and two hypochlorite controllers was equipped with a 2-inch monel metal balanced float valve, while 3-inch valves with iron bodies were used on the lime controllers. Each valve was connected directly with the balanced arm on top of the controller by means of the $\frac{1}{4}$-inch rod and turnbuckle as on the master controller. A glass sight tube was placed on each controller and on the master, with a graduated scale behind the tube. The result has been even more gratifying than was anticipated, and all troubles have been eliminated. The system automatically regulates itself with changing rates, and aside from a slight adjustment occasionally of the turnbuckles or cleaning of the valves no attention is required. Two triplex pumps, two motor-generator sets and complicated electrical apparatus have been eliminated, and there is no more fluctuation of levels in the system.

Liquid chlorine. Hypochlorite of lime was formerly used at Minneapolis in conjunction with filtration. At first the hypochlorite was added to the water upstream from the filters, but it was found that tastes and odors appeared in the filtered water during the summer months. The hypochlorite was then added to the filtered water and fewer complaints resulted.

In November, 1915, because it was found impossible to secure a year's contract for hypochlorite, liquid chlorine treatment was substituted for the hypochlorite. Three Wallace & Tiernan chlorine machines were installed, and as a result, the department will never return to the use of hypochlorite if it is possible to avoid it. There

have been no complaints of taste or odor arising from chlorine treatment since the beginning of the use of liquid chlorine.

Filter bottom troubles. The filters had not been in service sixty days before breaks occurred in the Tobin bronze strainer plates. At first the breaks were scattered, but they became so frequent that it was necessary to remove all center strainer plates from all filters. The brass wire screen that had been bolted to the ridge blocks to hold the gravel down became such a nuisance at this time that it was taken out altogether, the depth of gravel increased to 13 inches with a new size, $1\frac{1}{2}$ to 2 inch added. The filters have washed better without the screen.

Investigation showed that many of the center plates and a few side plates had failed. Most of the breaks, however, were in the center plates which were supported by yokes from above the plates, whereas the side plates were held in place by U-bolts from below. It was thought, therefore, that possibly the design of the center plates was at fault and F. W. Cappelen, city engineer, suggested reinforcing each sound center plate with $\frac{1}{8}$-inch sheet brass riveted longitudinally along the center line of the plate. The broken center plates were replaced with medium brass plates made up as needed. Many of the reinforced plates cracked along the edge of the brass strip and had to be removed.

Tests of the tensile strength and bending of the Tobin bronze were made on strips cut from plates that had failed, but the tests seemed to show that the metal met the original specifications. Meanwhile the breaks continued, and it became difficult to keep enough filters in service to supply the city with water.

A decision was made to re-design the strainer plate system, making the plates heavier, increasing the size of the holes in the plates from $\frac{1}{16}$ to $\frac{3}{32}$-inch and reinforcing the plates with bronze ribs. Inquiry was made from various users of naval bronze and all agreed that the best grade of Tobin bronze should be adequate for the city's needs. The plates and bolts were then ordered made according to plans and specifications rigidly drawn by the designing engineer and approved by City Engineer Cappelen.

The new plates and bolts were properly installed in one filter unit, and the filter placed in service. Breaks occurred and upon investigation it was found that the bolts in the center had failed. A few of the plates also had cracked.

All bolts were then tested in tension by a dead load of 800 pounds.

Bolts tested to failure in a testing machine straightened out at a load varying from 1420 to 1350 pounds. Other bolts bent through 180 degrees flat on themselves showed no fracture of the bent portion. The bolts tested to failure gave a unit tensile strength varying from 71,000 to 100,000 pounds per square inch. Carefully tested and inspected bolts and plates were then replaced in the filter and the filter put in service. Failures again occurred.

A new lot of bolts was then heated in a furnace to a cherry red, quenched in luke-warm water, tested to 600 pounds and put in place. They lasted about four weeks.

Strainer plates next began to fail. Laboratory tests were made to determine the effect of temperature changes upon the metal, also of electric currents, and of the water in the filters. These tests seemed to show no effect whatever upon the metal, which appeared to be sound. The mercuric chloride test was applied but without any result.

The company which made the plates and bolts suggested that possibly the cold working of the metal in making it up into plates and bolts might have caused a re-arrangement of the molecules. They suggested annealing the metal. Therefore, enough plates and bolts to equip one filter were heated in a furnace to a cherry red for one hour, then removed and slowly cooled. These plates and bolts were then placed in a filter and the filter put in service. The results were very gratifiying, no breaks occurring. The rest of the plates and bolts were then annealed in the same manner and after inspection and removal of any cracked ones, were placed in the filters. Only a few scattered failures have since occurred.

The medium brass plates and bolts installed in the filters have shown no failures whatever. Monel metal plates and bolts likewise having been used in one filter have shown no failures. All of the troubles were confined to Tobin bronze.

The U. S. Bureau of Standards made an investigation of the molecular structure of plates and bolts that failed and likewise of similar material that had not failed. Its conclusions based upon these investigations and on investigations of naval bronze failures elsewhere, are that the cold working of the metal and too little attention paid to annealing cause considerable internal stresses, which are responsible for the failures. It appears probable that hereafter monel metal will be used for strainer plates and bolts at the Minneapolis filtration plant.

DISCUSSION

JOSEPH RACE: The speaker wishes to know if the author has had any complaints regarding odor at Minneapolis due to the sterilizing treatment given to new mains. In Canada the speaker has noted several complaints of this character and they appeared to be due to a combination of the hypochlorite or chlorine with the asphalt paint used for coating the mains.

PROF. EDWARD BARTOW: Has the speaker any figures of the relative cost of liquid chlorine as compared with hypochlorite? The Central Illinois Public Service Company has made comparisons and reached the conclusion that liquid chlorine was much cheaper than hypochlorite.

MAYO TOLMAN: The point of application of the chlorine seems to have some influence on the taste and odor of the water. A certain town in West Virginia was forced to supplement a supply of water derived from driven wells with river water. A chlorination plant was installed to treat the river water, but the point of application was such that it was necessary to treat the well water also. It was found that when the river water predominated chlorine tastes were particularly noticeable but that when the well water predominated there was no taste, although there was no appreciable change in the amount of chlorine used or the total volume of water treated.

THEODORE A. LEISEN: Perhaps it might be pertinent to state conditions in Detroit, especially regarding the question of the aftergrowth. In the matter of taste, without any change in the quantity of chlorine, a perceptible taste has been found at certain times and not at others, the taste increasing apparently in proportion to the organic matter in the water. It might be interesting to give the record of Detroit water for three or four months. This record presents a rather remarkable example of surface water which at times may become polluted, and at times is polluted, and then again for a considerable period shows no sign of pollution.

The record covers December, 1915, January, February and March, 1916, when using about 1½ pounds of liquid chlorine per million gallons of raw water. In December it showed 11 bacteria per cubic centimeter on agar at 37°, and confirmed evidence of B. coli in 69

out of 231 samples. The treated water showed 3 bacteria on agar, and no evidence of B. coli in 230 samples. In January, the raw water showed 4 bacteria on agar and evidence of B. coli in 12 out of 210 samples. The treated water showed 2 bacteria and no evidence of B. coli. In February the raw water showed 3 bacteria and no evidence of B. coli. This was reduced to 1 bacterium in the treated water and no evidence of B. coli. In March the record went up to 19 bacteria and evidence of B. coli in 3 out of 260 samples of the raw water; there were 14 bacteria per cubic centimeter and no evidence of B. coli in the treated water. The samples for B. coli were 10 c.c. samples, and were taken at the pumping station at various points.

The chlorine is introduced at the shore end of the tunnel where it is fairly well agitated and then goes into what was originally intended for a settling basin but is so small that under present consumption conditious it really means simply a passage way to the pumps. The City Board of Health gets part of the samples taken every day, and their results confirm the Department's tests. The tap water samples taken near the pumping station and those taken down town are almost exact duplicates of the results mentioned, showing that in this instance at least there seems to be no additional growth in the passage to the city.

F. B. Leopold: The subject of coagulant piping has probably been of as much an annoyance as any other single item in the design and construction of filtration plants and many different schemes have been tried to minimize these troubles. If the experience of all the operators could be obtained, it would be possible to avoid these difficulties in construction more easily. The speaker has used almost everything that has been suggested for coagulant piping. One material has an advantage over another in one respect but it may have disadvantages which outweigh the advantage. After considerable experience with lead lined pipe the speaker will never attempt to use it in the future. In each case where it was used there was trouble because the lead lining had pin holes which allowed the solution to penetrate and attack the iron pipe. The speaker discontinued its use for several years and later made one or two additional installations but the result was practically the same.

It was next decided to try the composition conduit which is installed in Rock Island, Ill. There was some trouble experienced at first, as the author states. After some changes the last reports were

that it was satisfactory. On the strength of the work at Rock Island, St. Louis decided to try the conduit piping and it was installed originally. It was unaffected by the alum solution but, due to unequal expansion and contraction, it was continually breaking and causing trouble and was finally abandoned and lead pipe used in the place of it. The speaker has never since attempted to use this type of pipe for chemical solution.

It is probable that on the whole rubber hose has proved as satisfactory as anything. The plant at Flint, Mich., was completely equipped with rubber hose for solution piping. The great difficulty with this is, of course, the proper support for drainage. In order to take care of this at Flint, the hose was placed inside wrought iron pipe. This has been in use at Flint for some four years with very satisfactory results. It has the advantage of being readily removed and cleaned at low cost and also the advantage of being flexible. By putting on additional pieces of hose the point of application can be readily changed. For large plants, however, it is extremely expensive and is probably not as well suited for them as for small plants. In other words, the disadvantages of high cost would outweigh any of its advantages.

The speaker has several times seen the cast iron conduit used in Minneapolis and after several years use with the alum solution it seems entirely unaffected. It is not always convenient to place an open conduit for conducting the solution and many things have to be considered in determining what may be best suited for each condition. Lead pipe is very satisfactory for alum solution but it must be properly supported or it will sag and cause pockets in which deposits will take place, or if any weight is brought to bear on it, it may in time become closed at that point.

Regarding the concrete chemical solution tank, the author's experience is in line with that of many other operators. In the course of time an alum solution seems to disintegrate the concrete and the speaker has been making it a practice of late to coat the inside of the chemical tank with an asphalt coating which apparently obviates this difficulty.

The author's ideas of the esthetic side of filtration plant design are thoroughly in accordance with those of the speaker. However, it is practically impossible for a contractor or builder to inject into his plans very much for appearances' sake that will add to the cost of the plant. It has been the speaker's experience that when bids

are received on a plant that the first thing that is looked at is how many dollars it costs, and it is with the utmost difficulty that the average board can be persuaded to consider an analysis of what is being furnished for the dollars and cents in a comparative way. The engineer has more freedom in designing a plant for those things which add only to the appearance. Even when the engineer suggests the expenditure of money for the sake of good appearance, a board is slow to appreciate it until after the plant is built; then it can see that certain effects might be added which would greatly improve the appearance and not add a great deal to the cost and is perfectly willing to express regret then that it was not done.

Lewis I. Birdsall: There has been no trouble of the kind mentioned by Mr. Race. After emptying the pipe of the strongly treated water, the main is flushed for a while, and a test made to see that all of the free chlorine is eliminated. There have been no complaints whatever of the taste of chlorine in the water since the use of hypochlorite was abandoned in 1915.

At Minneapolis a dose of approximately 50 pounds of hypochlorite is used per million gallons of water in the main. A very strong residual chlorine content is desirable in order to obtain complete sterilization of the pipe. There are two ways of applying the bleach. If there is a manhole on the main the dry chemical can be dumped in it but better results have been obtained by mixing the hypochlorite with water and adding the solution as the pipe is filling. Great stress is laid upon the test for residual chlorine in the water as the pipe is being emptied after standing full for several days. Bacteriological analyses show the water to be absolutely sterile in all cases.

In answer to Dr. Bartow's question, it was found that one pound of liquid chlorine at Minneapolis was equivalent to 5 pounds of hypochlorite. The cost of hypochlorite in 1915 was 21 cents per million gallons of water treated. Last year, with liquid chlorine the cost was 27 cents per million gallons. That makes it look like a higher cost for chlorine; but when it is considered that hypochlorite cost 1½ cents per pound in 1915 and liquid chlorine 11 cents per pound in 1916, and that hypochlorite in 1916 in place of liquid chlorine would have cost as high as 15 cents per pound, it appears that the cost of hypochlorite would have been several times more than the cost of liquid chlorine in 1916.

The experience with changing the point of applying the bleach was as follows: The sterilizing agent was applied above the filters when the plant was first started in 1913 and complaints of chlorine in the water were numerous. It was suggested that the chlorine might possibly combine with the organic matter in the unfiltered water in such a manner that after the water was filtered and delivered to the consumers heating the water in the pipes would cause this unstable product to decompose and produce an odor and taste. Therefore, the sterilizing agent was added below the filters in a control chamber from which the water goes directly to the city or to the clear water reservoir. There has been only one case of aftergrowth in the water following sterilization and that was in April, 1914, when the gelatin count in the water from the clear water reservoir ran up to several thousand per cubic centimeter but the agar count remained practically the same.